NATIONAL PROJECT FOR DESIGN AND CONSTRUCTION STANDARDS
IN UNDERGROUND WORKS

(promoted by AGI, ANIM, GEAM, IAEG, ITCOLD, SIG, SIGI)

GUIDELINES FOR DESIGN, TENDERING, AND CONSTRUCTION OF UNDERGROUND WORKS

updated march 1997

Inserto del N. 51 di "Gallerie e Grandi Opere Sotterranee"

WORKING GROUP: **"DESIGN"**

Group leaders: Ing. A. Focaracci, Ing. P. Grasso

Group members

Dr. S. Chiesa
Ing. IM. Cicognani
Ing. IM. Colella
Ing. G. Forzano
Ing. A. Frassoni
Dr. G. Froldi
Prof. G.P. Giani
Prof. A. Lembo Fazio
Prof. S. Olivero
Ing. D. Peila
Prof. S. Pelizza
Ing. G. Rabajoli
Dr. G. Russo
Ing. F. Scarabellotto
Ing. R. Zianna

WORKING GROUP: **"CONSTRUCTION"**

Group leaders: Ing. G. Ceppi, Ing. A. Chiari, Ing. T. Silvestri

Group members

Ing. E. Arini
Geom. L. Arnoldi
Ing. E. Botti
Ing. L. Brino Jr.
Ing. L. Brino Sr.
Ing. R. Casale
Ing. G. Delli Veneri
Ing. R. Grandori
Ing. A. Lavorato
Ing. F. Michelotti
Adv. C. Orlando
Prof. M. Patrucco
Ing. E. Pizzarotti
Dr. M. Sapigni

COMITTEE OF PRESIDENTS OF ASSOCIATIONS

Coordinatore del Comitato dei Presidenti - **Ing. Adolfo Colombo**

Presidente IAEG - **Prof. Vincenzo Cotecchia**

Presidente SIGI - **Prof. Ing. Pietro Lunardi**

Presidente AGI - **Ing. Sandro Martinetti (Delegato Ing. Tito Silvestri)**

Presidente ITCOLD - **Dott. Morando Dolcetta Capuzzo (Delegato Ing. Carlo Niccolai)**

Presidente GEAM - **Prof. Ing. Renato Mancini (Delegato Ing. Daniele Peila)**

Presidente SIG - **Prof. Ing. Sebastiano Pelizza**

Presidente ANIM - **Prof. Ing. Carmelo Latino (Delegato Ing. Luigi Percivalli)**

NATIONAL PROJECT FOR DESIGN AND CONSTRUCTION STANDARDS IN UNDERGROUND WORKS

(promoted by AGI, ANIM, GEAM, IAEG, ITCOLD, SIG, SIGI)

GUIDELINES FOR DESIGN, TENDERING, AND CONSTRUCTION OF UNDERGROUND WORKS

Purpose and Scope of the Guidelines

Underground construction has developed considerably in the past few decades, so much so that it is now considered a key factor in future development of infrastructures. It is evident, for example, that in metropolitan and suburban transport underground structures allow for development of land use in harmony with the natural, social and economic environment.

In this period of renewal of national and European technical codes, seven Italian cultural associations which operate in the field of tunnelling, rock mechanics end geotechnical engineering proposed to contribute towards the implementation of common standards by jointly developing a National Project For Design And Construction Standards In Underground Works.

This Project has led to the present "Guidelines For Design, Tendering And Construction Of Underground Works" which may serve as a reference for all operators in this sector.

Guidelines for Design

These Guidelines refer to structures which require underground excavations (as defined in the Ministerial Decree of 11 March 1988) and consist of design recommendations for these structures: from the definition and analysis of tasks, through choice and optimisation of solutions to clear-cut definition of safety margins and reliability of forecasts.

The objective is to obtain a complete design which serves as a precise and comprehensive reference for those involved in the construction and which provides a reasonable and declared approximation of construction costs and durations that can be reliably used for interfacing with the parallel financial planning.

The intent should be to maintain a reasonable balance between the inevitable residual margins of uncertainties and the costs. But an effort must be made to reduce the degree of uncertainty to arrive at the levels which are accepted in other engineering works which are far less conditioned by subsoil variables. This goal can be achieved if at the design stage sufficient resources are dedicated to investigations aimed at defining a clear and reliable geological model and, from this, a parallel geotechnical model which can be developed by means of the calculations available in state-of-the art engineering.

In underground works, more than in other civil engineering activities, construction induces complex and often time-dependent soil-structure interactions. Design must, therefore, develop both of the basic aspects which determine the interaction: statics of the excavation and construction methods employed.

The basic concepts of this approach are generally well known to those engaged in the underground works but, in any case, it is useful to recall them:

- Excavation stability analysis must take into account the three-dimensional nature of the problem at the tunnel face. Already ahead of the tunnel, the excavation induces changes in the original state of ground stress and consequent deformations of the mass (soil or rock in which the excavation is taking place);
- The stress-strain relation of the mass after excavation can be schematically represented by three types of behaviour: elastic, elasto-plastic, failure;
- Development of ground deformation and, therefore, of possible instability of the face and walls, depends on the stress path induced by the excavations and on the physical, mechanical and structural properties of the ground. Analytical and experimental models must correctly account for both of these aspects and simulate the phases of face advancement and of reinforcement and confinement measures.

The success of the project in terms of construction times and costs, and the statics and maintenance required during operation, strongly depends on the method of excavation employed and the timing of the various construction phases.

After completion of the static analyses for the behaviour of an excavation, the design must specify the construction methods and procedures required for stability, safety and efficiency of a project during both construction and operation.

Detailed specifications must be provided in the design for each substructure: where it is to be employed (ahead of the face, at the face or in the tunnel behind the face), its function in the control of deformations and expected effects on the static conditions of the excava-tion, instrumental monitoring required to check the design assumptions and criteria for acceptance or requirements for changes in design during construction.

The Guidelines have been developed according to a reference scheme that is based on the following criteria:

- identification of the **"key points"** and their organisation in **"subjects"** representing the various successive aspects of the problem to be analysed and quantified during design;
- brief description of the various stages;
- indication of the most widely accepted criteria and methods.

The degree of detail of each **"key point"** (e.g. "site investigations") will depend on the peculiarities of the specific project and on the design stage. The three design (Progetto) stages are: Preliminary (Preliminare), Final (Definitivo), and Detailed (Esecutivo).

The Guidelines are organised around the following main themes:

A. General setting of the underground structure.
B. Geological survey.
C. Soil and Rock Mechanical studies.
D. Prediction of mechanical behaviour of soil or rock mass.
E. Design choices and calculations.
F. Complementary design work and tender documents
G. Monitoring during construction and operation.

The key points are listed in a sequence that follows the logical and chronological development of design.

In reality the design is developed by groups having different specialities in the field. These groups interact with each other, but actually operate autonomously according to the practice of their particular area of work. In any case, they all refer to a central co-ordinating, organisation which directs the project toward the goal. This direction refers to the logical order of the key points of the Guidelines.

Although no explicit mention is made, it is intended that, in any case, minimum standards as stipu-lated by law must be observed for all aspects involved in underground construction such as: safety and health at work; interference with the surrounding environment; insertion in and safeguarding of the environment; safety and efficiency during operation; material properties and methods for working them, etc.

The Guidelines have incorporated the distinction between "principles" and "application rules" as laid out in Eurocode 7. Considering its application to design procedures, the distinction should be intended as follows:

- according to the Guidelines, design of an underground structure develops through a series of "key points" (e.g., level B1);
- the Guidelines list the essential "subjects" to be treated for a correct development of the "key points": these subjects (e.g., level B1.1) can be assimilated with the "principles" of Eurocode 7 and must necessarily be analysed;
- The Guidelines frequently provide a logical sequential order for treating the subjects (e.g. level B1.1.1). This further development can be intended, in the same of Eurocode 7 "application rules", as a recommended but not compulsory procedure. In other words, the designer can analyse the subjects in a different manner at his own discretion as long as he can assure their complete rational development.

Guidelines for Tendering and Construction

The second part of the Guidelines considers the con-struction of underground works, with suggestions and recommendations for the various time steps and areas of expertise involved:

- notice for tender;
- drawing up and awarding a contract;
- system of payment for construction work done;
- technical specifications and standards;

It should be borne in mind that the drawing up of these Guidelines began in a period of particular confusion in legislation. Since the beginning of 1994 (approval in Parliament of the "Merloni" Bill No. 109), there have followed a series of often contradictory decrees, bills and proposals on the subject of public works (Bill n. 216 of 2/6/95 named "Merloni bis"; Ministerial decree of 20/2/97 known as "Merloni ter").

With this situation, it was considered important that experts in this sector of public works, so particular as to require special attention even in Parliament, should make their opinions known.

While waiting and hoping for parliament to legislate once and for all on the matter, we assumed, in drawing up our Standards, that some of the policies of particular importance to underground works that have already been proposed to parliament would in fact become low:

- tenders made only on basis of complete and "detail" designs;
- limited changes in design admitted after contract is awarded;
- the possibility for a contractor to request, for no increase in price, only non substantial changes to the design solution;
- contract prices totally or partially on basis of "quantity measurements" rather than on "lump sum" for certain categories of projects: underground works, foundations, marine works, land reclamation and river works.

A. General setting of the underground work.

A.1 General setting of the work and its relationship with the general design

A.1.1 Functional requirements

A.1.1.1 Location, route, interference

A.1.1.2 Definition of the geometry of the work

A.1.2 Design constraints

A.1.3 Environmental aspects

A.1.4 Comparative analysis of alternative routes

Underground construction may concern either new (to be built) or previously existing structures. In both cases design should choose solutions which minimise interference of new works with normal operation of existing infrastructures, by means of suitable construction techniques or appropriate scheduling of the works.

Description of the functional requirements of the tunnel consists in defining the principal geometric elements such as the cross section type, the hydraulic cross section, etc. Definition of detail in the section type also requires information on the tunnel length, the design velocity, transverse and longitudinal ventilation systems, procedures for minimising environmental impact which take into account national and local land use constraints.

Route studies should be conducted on the basis of updated maps with scale and detail according to design requirements.

Choice of route shall be based on technical and economical comparisons of alternative solutions (for example, using the same criteria as laid out for environmental impact evaluations). Special attention shall be placed on indication of existing buildings and structures, specifying their type and consistency. Should the structure require ventilation, air vents and systems should be clearly located so as to verify their structural and environmental compatibility.

Special attention shall be given to the use of materials and procedures which maintain quality of intercepted water and which minimise interference with the water table, etc.

The comparison between alternative possibilities should make use of the established methods of comparative analyses (e.g., multicriteria).

A.2 Critical examination of previous design stages

A.2.1 Collection and examination of technical documents

A.2.2 Assessment of the degree of completeness of the design

Before passing to the final and detailed design, an examination of previous design phases is made. Design data are updated with new information obtained so as to eliminate the mistakes which may limit project effectiveness.

In order to assess the degree of completeness of the design, in the various to design levels, it is considered useful to subdivide the problems into different types of activity.

A.3 Codes and standards

Together with the existing national codes (in soil and rock mechanical engineering, Ministerial Decree 11 March 1988 and Public Works Ministry Circular no. 30483 of 29 September 1988), it is recommended to follow the standards of formally recognised institutions (AIPCR, CNR, UNI, AGI, CEI, IMQ), EU directives and specific requirements of local authorities.

A.4 Recommendations for subsequent stages of design and construction

A.4.1 General technical judgement of project and recommendations

A.4.2 Indication of possible design adjustments

A.4.3 Considerations regarding possible alternatives

A.4.4 Special conditions for tendering and construction

When completing a design at a given level, it is important to outline the critical aspects and subjects which require further study and investigations in subsequent design phases.

Since the construction technology (mechanised or traditional excavation, etc.) has an important influence on structural geometry, a detailed description should be given so that the Owner can judge the consequences of a given choice.

B. Geological survey

B.1 Acquisition of available data

B1.1 Literature review

B.1.1.1 Books and articles

B.1.1.2 Maps

B.1.1.3 Aerial photographs

B.1.1.4 Geophysical data

B.1.1.5 Wells and water springs

This allows to optimise and structure the information already available and acquired by third parties. The work should concentrate on research documents, studies made by other consultants, articles in specialist reviews and magazines, maps, aerial photographs, geophysical data, hydrogeological surveys, etc. A summary of the information collected shall be duly commented on in a special chapter.

B.2 Preliminary geological model

B.2.1 Structure
B.2.2 Stratigraphy
B.2.3 Geomorphology
B.2.4 Hydrology and Hydrogeology

It is the initial model for geological interpretation, based both on information available and on a preliminary outcrop survey; it is required for planning the investigations. As a rule, It should describe the geological structure, stratigraphy, and geomorphology and hydrogeology, indicating the structural units present and their relationship, the lithology and possible vertical and horizontal stratigraphic variations, morphological, structural and tectonic indicators. Geological and thematic maps, longitudinal profiles, cross sections and stratigraphic columns shall be prepared in a scale suitable for design.

B.3 Site investigations

B.3.1 Evaluation of interaction with geotechnical and geomechanical investigations (see point C2)
B.3.2 Planning of site investigations
B.3.2.1 Type and location of direct investigations
B.3.2.2 Type and location of indirect investigations
B.3.2.3 Analysis of results

Planning of investigations is aimed at reconstruction of the geology and hydrogeology, but it is also the basis for the geotechnical and geomechanical investigation plan. It must be co-ordinated with the latter in order to optimise the methods and means of investigation. The description shall cover the type, quantity and location of the direct and indirect investigations required. Direct investigations include structural geological surveys, drilling, testing in boreholes, mineral, petrographical and paleontological determinations, installation of instrumentation for monitoring and, if necessary, excavation of a pilot gallery. Indirect investigations are essentially geophysical and include borehole logs, seismic refraction and reflection and geoelectric and gravimetric investigations. Continuous on-site supervision of investigations and examination of the results can check the validity of the preliminary geological model and, consequently, determine the necessity of modifying or otherwise completing the original investigation plan.

B.4 Final geological model

B.4.1 Structural setting
B.4.2 Meso-structural features
B.4.3 Lithostratigraphic features
B.4.4 Mineralogic and petrographics features
B.4.5 Reliability of the geological model

The model summarises all of the geological information obtained. On the basis of the preliminary geological model and subsequent investigations, a structural setting is defined giving relationship between the different units that are present and principal alignments in the area. The results of the investigations should be sufficient to define the structure and lithostratigraphy of the masses crossed by the underground project. These studies shall also bring to a complete definition of the mineral and petrographical characteristics of the different rock masses present in the area., dividing the lithology into suitable classes. Reliability of the geological model and definition of critical points shall be established according to the recognised complexity of the geology and the extent of the investigations carried out. The final version of the drawings developed for the preliminary setting and listed at point B2 shall be prepared.

B.5 Geomorphology

B.5.1 Geomorphologic setting
B.5.2 Interaction between morphogenetic dynamics and designed structure

This topic deals with the definition and characterisation of geomorphologic phenomena in relation to the construction and operation of the designed structure. The general geomorphologic setting shall be described, with special details for the areas around tunnel portals and in areas with low rock cover., A classic geomorphologic map shall be prepared, including information on geomorphologic dynamics, types of instability and degree of activity.

B.6 Hydrology and hydrogeology

B.6.1 General Hydrology and hydrogeology
B.6.1.1 Hydrological context
B.6.1.2 Features of hydrogeological structures
B.6.1.3 Underground water regime
B.6.1.4 Evaluation of hydrogeological risk
B.6.2 Water chemistry
B.6.3 Structure-acquifer interaction
B.6.4 Presence of other fluids

The surface and underground water flow properties are defined. The data collected shall permit a determination of the area hydrology and hydrogeology with possible interaction with the project. Surveys, piezometric and surface measurements, and chemical testing shall lead to the characterisation of the aquifers present in the area and to an evaluation of the hydrogeological risk.

Surface and underground water properties shall be determined by testing the samples taken from piezometers installed in boreholes, from wells, and from water springs in the area.

The data should be sufficient to allow determination of the possibility of interaction between the structure and underground water or other fluids that may be present within the masses (e.g. various gases).

B.7 Geothermal studies

The various studies and investigations shall allow determination of the thermal gradient, presence and flow of geothermal fluids, and forecast of rock temperature in the tunnel.

B.8 Seismicity

B.8.1 Seismicity of the area and neotectonic aspects
B.8.1.1 literature review of seismicity
B.8.1.2 seismic classification
B.8.1.3 identification of seismic structures

A detailed study shall be made of the seismicity and neotectonics of a wide zone surrounding and including the project area. Specialised literature (books, magazines, catalogues) shall be examined for data on frequency and characteristics of earthquakes in the area. A detailed study shall be conducted to determine the active structures which could possibly generate seismic events. The studies shall lead to the definition of a theoretical "design earthquake", having a given intensity, recurrence period, and dynamics.

C. Geotechnical-geomechanical studies

C.1 Preliminary evaluation

C.1.1 Review of data from geological study
C.1.2 Review of data from literature
C.1.2.1 Review and analysis of data from books and magazines
C.1.2.2 Review and analysis of data from studies in similar contexts

Examination of the geological study and of available information from literature shall precede the planning of investigations and tests.

C.2 Geotechnical and geomechanical investigations

C.2.1 Evaluation of the relation-ship with site investigations (point B3)
C.2.2 Planning of investigations and tests
C.2.2.1 Planning of laboratory investigations and tests
C.2.2.1.1 Specifications for sampling
C.2.2.1.2 Tests for physical characterisation of soil or rock: type, number and original location of samples.
C.2.2.1.3 Tests for mechanical characterisation of soil or rock (strength, deformability): type, number and original location of samples.

C.2.2.1.4 Mineral and mechanical tests for soil with swelling properties: type, number and original location of samples.

C.2.2.2 Planning of in-situ investigations and tests

C.2.2.2.1 Tests for mechanical characterisation of soil or rock (strength, deformability): type, number and location of tests.

C.2.2.2.2 Tests for hydraulic characterisation of soil or rock: type, number and location of tests.

C.2.2.2.3 Tests for determination of the natural state of stress.

C.2.3 Summary of results

C.2.4 Additional investigations

Laboratory and in-situ investigations and tests, required for geotechnical and geomechanical characterisation, shall be planned after optimising interaction with on site geological investigations. After completion, the consultant shall analyse the results and determine if it is necessary to extend the investigations and tests. At the planning stage, objectives, criteria and detailed plan of investigations and tests (type, number, location) shall be described. After completion of the investigations and tests, individual and overall results shall be analysed, including evaluating their significance and coherence and examining whether the initial objectives have been satisfied or if further investigations are necessary. Data processing shall make use of statistical methods and illustrate the theoretical distribution and actual dispersion of the results.

C.3 Soil or rock mass characterisation

C.3.1 Soil or rock mass structure

C.3.1.1 Geotechnical complexity

C.3.1.2 Type and frequency of main discontinuity systems

C.3.1.3 Preliminary geotechnical model

C.3.2 Soil or intact rock characterisation

C.3.2.1 Definition of geotechnical and geomechanical parameters

C.3.2.2 Technical classification

C.3.3 Mechanical characterisation of discontinuities

C.3.3.1 Behaviour models and failure envelopes

C.3.3.2 Definition of shear strength and deformability parameters

C.3.4 Hydraulic properties of the soil or rock masses

C.3.5 Geomechanical classification of rock masses

C.3.6 Geotechnical and geomechanical models

C.3.6.1 Physical and mechanical properties from literature

C.3.6.2 Quantification of scale effect

C.3.6.3 Behaviour models and failure envelopes

C.3.6.4 Geotechnical models of soil and characterisation of the different groups

C.3.7 Geotechnical and geomechanical zoning

The recommended procedure for geotechnical and geomechanical characterisation consists of analysing the masses both according to their component parts (geological material and discontinuities) and as a whole.

Initially the general structure of the mass shall be defined, indicating whether it is soil or rock, the elementary geotechnical complexity (AGI, 1979) and the principal structural features, including the representative volumetric element. For each system of discontinuities (intrinsic of the particular rock and/or extrinsic), the type, frequency, and geometric and geotechnical bedding characteristics shall be given.

After defining the general context through a preliminary geotechnical model, the geological material of the masses (intact rock or soil) shall be characterised, without considering extrinsic discontinuities, by defining the index properties, strength and deformability (peak and residual), in saturation and stress conditions as assumed in design. Anisotropic and/or heterogeneous conditions, rheologic properties, alterability and sensitivity to water (swelling, erodibility, etc.) shall be included. It is generally recommended to use widely recognised parameters for classification.

For the different discontinuity systems identified through structural analysis, representative strength and deformability parameters shall be defined for the expected stress conditions, preferably using the plots of shear stressus deformation and shear stressus normal stress.

The geotechnical and geomechanical studies aimed at zoning and characterising the masses shall take into consideration all available information, using different methods of analysis and comparison of the results.

The hydraulic characteristics of the masses shall be defined along the design route, indicating the main parameters which govern flow (water head, permeability, etc.).

In particular conditions, it may be useful to refer to the geomechanical classifications, in which case it is necessary to illustrate the criteria followed for choice of the most suitable classification system and to quantify the input parameters and to define the quality indexes.

The choice of the representative parameters, and of the consequent geomechanical reference groups, shall be made on the basis of direct determinations available, accepted empirical relationships with measured variables, correlations - if required - to take into account the scale effect, and of other documentation obtained by studies conducted in similar geomechanical contexts. Each geomechanical group shall be associated with a behaviour model and with a failure envelope, defining the intrinsic curves on the "stress-strain", "normal stress-shear stress" and "major-minor principal stress" planes.

The results of the characterisation procedure must allow a correct reference to be made to the scale of the problem and to a continuous/continuous-equivalent or discontinuous geotechnical model.

After defining the groups with comparable geomechanical properties, the ground along the design route shall be zoned accordingly.

C.4 Natural state of stress

The principal stresses shall be defined along the design route in terms of the original stress conditions at the design elevation, as determined by in-situ tests and/or through empirical procedures.

D. Prediction of mechanical behaviour of the masses

D.1 Subdivision of the route into "homogeneous" zones

The design route shall be subdivided into stretches on the basis of:

- Lithology of the formations
- Geotechnical and geomechanical properties
- Hydrogeological conditions
- Excavation Geometry
- Depth of excavation
- Natural state of stress
- Surface or underground constraints

D.2 Evaluation of the excavation stability conditions for each homogeneous zone

D.2.1 Calculation of behaviour of face and profile of excavation without support

D.2.1.1 Establishment and localisation of mechanisms of instability

D.2.1.2 Influence of underground water on stability of face of excavation

D.2.1.3 Time effect on conditions of stability

D.2.1.4 Assignment of behaviour category for each homogeneous zone

The behaviour of the excavation without support is predicted using suitable methods of calculation showing,. for each defined homogeneous stretch, the type and entity of forms of instability induced in the short and long term. Within each homogeneous zone, the structure shall be divided into stretches according to the behaviour category to which it belongs in relation to the stress conditions to be expected on the profile of the excavation.

In each stretch, it shall be determined whether, after excavation, the ground at the face and around the profile is in an elastic or elasto-plastic state and, in the latter case, whether the stress conditions would produce immediate failure.

According to the type of behaviour and the computational method used, a suitable safety factor is chosen to assure stability of the face and profile.

In case of tunnelling below water level the behaviour of the excavation in hydrodynamic or hydrostatic conditions shall be determined, taking into account the hydrogeological constraints as described at following point.

D.3 Surface and underground constraints

- D.3.1 Effect of underground excavation on the surface
  - D.3.1.1 Definition of displacements acceptable for structures
  - D.3.1.2 Definition of acceptable limits for relaxation of slopes
  - D3.1.3 Calculation of subsidence
  - D3.1.4 Estimation of subsidence effects on structures and comparison with predefined limits
- D.3.2 Ef-fects of excavation on the surrounding mass
  - *D.3.2.1 Definition of acceptable stress-strain variations on the underground structures and on the surrounding rock (i.e., displacements, stresses, plastic zones)*
  - *D.3.2.2 Calculation of the variations in the stress-strain field*
  - *D.3.2.3 Comparison of results with predefined limits and determination of general working criteria*
- D.3.3 Effects of tunnelling on existing hydrogeologic equilibrium
  - *D.3.3.1 Hydrogeologic balance within the mass*
  - *D.3.3.2 Estimation of flow rates induced by excavation*
  - *D.3.3.3 Impact on wells, springs, and subsidence*

If the new underground structure is to run near the existing structures (above or below ground), acceptable displacements induced by excavation of the designed structure must be defined. For shallow underground structures, which underline urban centres, infrastructures or unstable slopes, it is necessary to determine the effects of underground excavation on the ground surface (maximum expected displacement and extension of area affected) and on the structures and slopes in the vicinity. According to the type of structure present. acceptable limits of displacement and distortion shall be defined.

In the case of twin tunnels and of tunnels near existing underground structures, an adequate study of the effects of the excavation on the pre-existing state of stress and strain shall be conducted. It shall be necessary also to define the limits of acceptability of induced stresses, strains, and extension of plastic zones, on existing underground structures and on rock pillars which separate twin tunnels.

The hydrogeological and structural models shall allow determination of the interaction between underground structure and water, with quantification of flow rate induced into the excavation, variation in hydrogeological equilibrium, and effect on wells and water springs.

D.4 Preliminary design of methods of excavation and support

- D.4.1 Study of different methods of excavation and support: traditional and mechanised
  - *D.4.1.1 Review of literature describing experiences in similar contexts*
  - *D.4.1.2 Definition of criteria and determination of safety factor*
  - *D.4.1.3 Evaluation of the effects and modifications induced by different excavation methods on the natural characteristics of the ground and the original state of stress*
- D.4.2 Choice of general criteria for construction
  - *D.4.2.1 Study of preliminary solutions, with particular reference to mechanised methods*
  - *D.4.2.2 Study of alternative solutions (route, excavation methods, advancement sections, and support)*

The excavation methods, stabilisation techniques, type of lining for each homogeneous zone according to its specific problems, behaviour category, and constraints shall be critically reviewed.

A "multicriteria" comparison between traditional construction techniques (excavation, stabilisation of phase 1, final lining) and mechanised methods (open or shielded TBMs, with various degrees of automation) shall pinpoint the advantages and disadvantages in terms of system "flexibility" in relation to the specific project problems.

After determining the statically most efficient excavation profile, the effects of the different construction techniques on the natural properties and state of stress of the mass shall be estimated.

Construction times and costs and residual risks shall be included in a comparison of the methods.

E. Design choices and calculations

E.1 Choice of excavation techniques and support measures for each homogeneous zone

- E.1.1 Definition of applicable methods of excavation
- E.1.2 Design of the excavation method
  - *E.1.2.1 Traditional methods (drill and blast, mechanical methods)*
  - *E.1.2.2 Mechanised methods (TBM, full face shield)*
- E.1.3 Definition of section type
  - *E.1.3.1 Statically most efficient profile in relation to function of structure.*
  - *E.1.3.2 Characterisation of the best excavation sequence referring to the stress-strain control of the cavity.*
    - E1.3.2.1 Analytical methods
    - E1.3.2.2 Other experiences in similar contexts
- E.1.4 Design of the stabilisation interventions
  - *E.1.4.1 Evaluation of the actions that must be applied to guarantee the satisfactory stability conditions*
  - *E.1.4.2 Evaluation of the effectiveness of the interventions.*
    Mechanisism of action and stabilising effect of the adopted supports.
  - *E.1.4.3 Choice of the interventions*
    - E.1.4.3.1 Numerical comparison between different geometries and different methods of support
    - E.1.4.3.2 Improvement of safety factor with supports
  - *E1.4.4 Definition of zones of application of the support measures*

E.2 Structural design

- E.2.1 Design loads
  - *E.2.1.1 Definition of loads in different phases of construction and during operation*
- E.2.2 Model of construction phases
  - *E.2.2.1 Stress-strain behaviour of excavation as designed*
- E.2.3 structural design of final lining
- E.2.4 Design of finishings (e.g. grouting for filling voids and improvement of rock properties and waterproofing of the ground around hydraulic tunnels, etc.)

E.3 Evaluation of the safety index

- E.3.1 Evaluation of the safety factors
  - *E.3.1.1 Choice of admissible safety factor according to the method used for computation*
  - *E.3.1.2 General safety factor of structure and safety factors for specific substructures*
- E.3.2 Crisis scenarios and collapse hypothesis

E.3.3 Definition of integrated, counter measures to be taken during construction, taking into account the most pessimistic assumptions

E.4 Design optimisation

E.4.1 Probabilistic evaluation of construction times and costs for the design solution

Suitable calculation programs can permit data processing of design parameters aimed at providing a detailed prediction of costs and times for the different construction phases while accounting for the residual uncertainties in design parameters.

F. Design of auxiliary work and tender documents

F.1 Design of auxiliary works

F.1.1 Design of portals

F.1.1.1 Choice of portal type

F.1.1.2 Structural design of portal works

F.1.1.3 Final (environmental) rehabilitation

F.1.2 Ventilation systems (shafts, tunnels, etc.)

F.1.3 Monitoring plan

F.1.3.1 Monitoring during construction

F.1.3.2 Monitoring during operation

F.1.4 Disposal and borrow areas

F.1.4.1 Quality and volume of muck

F.1.4.2 Quality and quantity of concrete aggregates required

F.1.4.3 Design of cut and fill

F.1.5 Ancillary works (lighting, ventilation, waterproofing, etc.)

F.1.6 Construction sites and access roads

F.1.7 Environmental impact study

The portals are designed taking into account the environmental, constructional and operational (visibility, non-reflectance, etc.) issues. Availability of construction material (stonefacing, grassing, etc.) shall be considered.

The portal design includes all details (drains, etc.) which shall be adequately illustrated in the drawings.

The design shall contain a plan for monitoring tunnel stability (extrusion, convergence, during operation of the tunnel, surface displacements, stresses in lining). Monitoring should also be carried out for checking its long-term stability.

Results of geological investigations shall be useful to evaluate the possibility of re-use of excavated material. Study of the disposal areas for the excavated material shall be included in the design.

Forced ventilation systems shall be included in road tunnel design so as to dilute vehicle exhaust fumes. A.I.P.C.R. recommendations for calculation can be followed.

The design of ancillary works shall include typical drawings prepared, taking into consideration the various aspects involved (luminosity variations at portals, space for vehicle recovery after accidents, pavement details, monitoring of traffic flow through magnetic spires, emergency niches, space for technological systems, etc.).

The site plan shall indicate the camps for workers' quarters, location of plants and machinery, existing or required roads to connect the main construction to the disposal and borrow areas.

F.2 Tender documents

F.2.1 Technical documents which form part of the contract

F.2.1.1 Design documents and technical specifications

F.2.1.2 Quality plan

- design during construction
- construction (interaction with design)

F.2.2 Plan for safety and co-ordination

Technical documents for tender consist of the necessary drawings and specifications required to completely define the works to be implemented, their functional requirements and, at the Owner's discretion, methods for construction and procedures for auditing and acceptance.

With the new directives on quality assurance (EU dir. 93/38), the Owner can require presentation of a quality plan which specifies responsibilities, procedures, and checks to be made in order to assure a correct correspondence between the design and construction.

The recent Decree, no. 494 of 14 August 1996, makes it compulsory for the detailed design to contain a plan for safety and co-ordination (Articles 12 and 13).

G. Monitoring during construction and operation

G.1 Monitoring during construction

G.1.1 Geological survey

G.1.1.1 Direct investigations

G.1.1.2 Indirect investigations

G.1.2 Hydrogeological measurements

G.1.2.1 Flow rate

G.1.2.2 Temperature, chemistry, aggressiveness

G.1.3 Geomechanical measurements

G.1.3.1 Geomechanical measurements

G.1.3.2 Analytical evaluation of the rock mass properties

G..1.3.3 In-situ tests

G.1.4 Monitoring stress-strain response of the tunnel face and profile

G.1.4.1 Extrusion measurements

G.1.4.2 Convergence measurements

G.1.4.3 Strain measurements in the rock mass

G.1.4.4 Stress measurements

Direct and indirect measurements of the state of stress in the tunnel surroundings

G.1.5 Monitoring the state of stress and strain in the linings

G.1.6 Effectiveness of consolidation and stabilisation measures

G.1.6.1 Direct measurements and tests

G.1.6.2 Indirect measurements and tests

G.1.7 Monitoring nearby structures above or below ground

G.1.7.1 Displacement and strain measurements

G.1.7.2 Vibration measurements

G.1.7.3 Monitoring of dust, pollution and noise

G.2 Checking validity of design and adjustment during construction

G.2.1 Comparison between design assumptions and measurements during construction

G.2.2 Adjustment of design according to the observed differences

G.3 Auditing

G.3.1 Structural auditing

G.3.2 System auditing

G.4 Monitoring during operation

G.4.1 Monitoring of stress and strain in ground-structure complex

G.4.2 Hydrogeological measurements

G.4.2.1 Flow rate

G.4.2.2 Chemical content, temperature, water aggressiveness

G.4.3 Surveys

G.4.3.1 Consistency

G.4.3.2 Tunnel deformations small

G.4.3.2.1 Vertical and horizontal displacements

G.4.3.2.2 Convergence

G.4.3.3 Strain and displacement of the ground and structure

G.5 Maintenance plan

G.5.1 Structures

G.5.1.1 Water collection and conveyance works

G.5.1.2 Metal protection works

G.5.1.3 Concrete protection works

G.5.2 Systems

G.5.2.1 Ventilation

G.5.2.2 Water pumping

G.5.2.3 Safety

G.5.2.4 Fire protection (and static consequences on structures)

H. Essential documentation for calling tenders and duties of the owner

The Owner, in order to call tender offers, shall provide to the Tenderers the following documents and data:

H.1 Detailed Design
including - but not limited to - tender drawings, plans and longitudinal profile, works description, specifications, programme outline, bill of quantities and individual price estimates

H.2 Environmental Impact Report

H.3 Definition of the work areas and the logistics, with clear indications of environmental and/or road access limitations

H.4 Definition, where necessary, of the disposal and borrow areas (for which actual availability has been confirmed)

H.5 Site acquisition plan and programme, with clear definition of relevant limitations, if any

H.6 Connection points for power and telephone , for road transport, for potable water and their availability;

H.7 Disposal points of site waters

H.8 Access points

H.9 Applicable road and traffic regulations

H.10 Earliest and latest timings for completion of the works and expected duration

H.11 Statement, to be undersigned also by the designer, as to time- and cost- reliability of the project forecast (not less than 80 %). The degree of uncertainty has to be related to the thoroughness of investigations and the level of expenses incurred by the owner in carrying out the geo-engineering investigations, on which the design has been based.

For the purpose of the actual construction of the works, the detailed design shall describe in a Geotechnical Baseline Report, GBR (or geological-geotechnical synthesis for construction) the expected behaviour of the rock mass, including convergence, stability conditions, overbreak risk and extent, necessary stabilisation actions, the necessity of special exploration or counter measures to be adopted at the face and generally the construction methods to be employed.

The Tenderers shall be informed not only about the dimensional elements of the Works, but also of the various functions and requirements of the individual components, so that the project documentation and the construction concepts are fully integrated. In particular, the Tenderers shall be provided with all the data and monitoring results of the behaviour of the rock mass and also with all the results of the investigations and of the evaluations. It is the duty of the Designer and of the Engineer to require during the works that investigations and monitoring of the behaviour of the rock mass be carried out. They have to instruct how these shall be performed, while the responsibility for the interpretation of the relevant results shall remain entirely theirs [1].

[1] The assistance to and the activities relating to investigation and monitoring shall be compensated at the rates to be inserted by the Tenderer in the Bill of Quantities for the relevant quantities indicated therein.

The following instructions must form an integral part of the design:

- the long term waterproofing in respect of underground water inflows;
- the environmental protection of the underground waters during and after construction;
- the collection, withdrawal and drainage, plus purification if necessary, of all waters during construction;
- final disposal of all the collected waters;
- permanent landscaping of the borrow - and disposal - areas.

The potential to influence either temporarily or permanently the underground water tables or springs , if any, shall also be considered. In such case the relevant and appropriate environmental authorisations shall be secured before calling for tenders. The Tenderers shall be informed about relevant potential responsibilities and the amounts set aside for compensation, if any.

The Tenderers shall be advised of all the available and necessary informations about local conditions (geological, geotechnical, geomechanical, hydrogeological, environmental), which could influence the performance of the Works.

Should the Designer consider necessary to adopt specific measures, equipment and / or materials, all these shall be specified in the Tender Documents.

The design may provide alternative construction methods for a specific local condition. In such case the Tenders shall refer to a single option.

The procedures to verify and dovetail during construction the detailed design are integral to the design itself.

Prior to calling for Tenders the Owner shall have already obtained - or shall reasonably ensure to acquire 'just in time' for the Works - all the authorisations and / or permits from the relevant Authorities connected with the Works.

Further, the Owner must secure all the project financing necessary for the Works. An official site visit(s) to all the Work areas shall also be organised, requiring attendance by all Tenderers, followed by a clarification meeting for a questions and answers session.

The Tenderers shall be given the opportunity to consult all the remaining documentation not included in the Tender Documents and to inspect all the existing samples. To that end the Owner shall provide a complete list of all the documentation available, indicating how and when such consultation could take place.

Any tendering procedure shall always evaluate the opportunity, by so stating it in the Tender Forms, to allow the Tenderer to propose in his Tender value engineering alternatives, providing time- and / or cost- benefits, except that the right to approve / disapprove it shall in any event remain with the Owner.

For portions of the Works to be performed by specialist companies, the Owner shall require the Tenderers to name in their offer the intended Subcontractors.

The time allowed to the Tenderers for making their offers shall be consistent with the type, magnitude, and complexity of the Works.

I. Documents required for prequalification (v. Art. 23 of law 216/95)

I.0 With reference to the EEC directives and article 23 of the law 216/95, the underground works shall be awarded by confidential tender, either to the lowest offer determined by unit rates or to the offer most advantageous economically

I.1 Company's organigram and curricula of the key management personnel

I.2 References of similar works performed in the last five years and being currently performed, of magnitude commensurate to the tender, with limits, if any, indicated by the regulations of the law 216/95

I.3 Copy of the last balance sheets

I.4 Bank references

I.5 Technical office organisation

I.6 Quality assurance system, if any

L. Documents to be submitted with the tender and duties of the tenderer

L.1* Comprehensive quotation of the tender form

L.2 Statement of the time necessary to start the works after award. The statement must be consistent with the forecast of the owner, indicated in H.10 above

L.3 Statement about the timings for delivery of the various documents of the design for construction, which are indicated to be the responsibility of the prospective Contractor, and nomination of the (Contractor's) Designer to be approved by the Owner

L.4 General programme of the Works

L.5 Detailed programme of the first four months of work

L.6 Expected 'normalised' cash-flow consistent with the programme of the Works

L.7 Detailed analysis - along the guidelines given by the Owner - of the most significant unit prices indicated by the Owner, which concur to make up at least 75% of the Tender sum. If the Tenderer submits an additional alternative offer, nevertheless the above analysis shall also be made for the 'basic' offer. Each analysis shall give details of the mark-ups foreseen by the Tenderer for overheads and profit

L.8 Technical report inclusive of:

L.8.1 description of the internal and external establishments relating to the production, logistics, and environmental protection

L.8.2 description of operating methods and work sequences

L.8.3 selection criteria of the main plant and equipment

L.8.4 sketches and drawings in relation to the above

L.8.5 organisation of production and maintenance shifts and work timings

L.8.6 site organigram and workforce utilisation plan

L.8.7 Quality Assurance Manual

L.8.8 other information required by the design specifications

L.8.9 list of plant and equipment, with characteristics, warranties and maintenance plan, etc.;

L.9 Safety plan

L.10 Indication of the portions of the Works to be sublet to specialist Subcontractors, with list of the relevant prequalified Subcontractors

L.11 Preacceptance (to avoid Tender disqualification) of the Owner's right to correct arithmetical errors, if any, contained in the tender.

Each Tenderer shall participate to the Site visit(s) organised by the Owner and to the subsequent questions and answers meeting for clarifications.

Each Tenderer shall also consult the documentation not included in the Tender Documents, but made available by the Owner in the place and at the time indicated. In the alternative, should the Tender Documents so provide, the Tenderer shall purchase such documentation.

M. A criteria for payment under the contract

The Contract shall provide a method of payment by Bill of Quantities, with all-inclusive items paid as measured. Lump sums, if any, could be envisaged for the site establishment and the portals.

The detailed design of underground works shall possibly indicate a suitable number of "typical sections" and the lengths in which they are foreseen.

Each "typical section" shall show the quantities of all the works within, to which (quantities) the 'basic' rates shall be applied. The design shall also indicate the application limits of the "typical section" as well as the test- and adjustment- criteria.

Thus the Tenderer will be able to make an offer at 'basic' unit rates, to be expressed for payment purposes as inclusive prices per meter of "typical sections".

The price for a "typical section" is inclusive of all the work components therein. These can be varied by the Engineer, to optimise the application of the design concept, within plus or minus 5 % of the price of the "typical section" without any further variation of the price itself [2].

The final price of the Works shall generally be the sum of the unit prices of the "typical sections" multiplied by the relevant lengths encountered in the tunnel. No further compensation shall be considered for possible variation of the frequency and distribution of each "typical section". The costs inherent to the presence of underground water and gases, in excess of the thresholds indicated by the design, are not deemed to be included in the typical sections prices and are to be separately measured and paid.

The Documents shall also specify the conditions for applying liquidated damages for late completion of the Works and their amounts and, if applicable, a bonus for early completion.

N. Variations

Changes to the detailed design of the project are allowed at the time of Tender only if proposed by the Tenderer and accepted by the Owner or during the Works only for specific instances listed hereunder.

Variations at time of tender (only if specified in the Tender forms)

The variations proposed by the Tenderer could refer to alternative construction methods for some or all of the "typical sections" (e.g., mechanised rather than conventional excavation) and in any event should provide the Owner either cost- or time-savings.

They have to be accompanied by a complete design for construction with graphs, calculations, and cost evaluations (Bill items, quantities, analysis) as necessary for a thorough evaluation by the Owner.

The alternative design, signed by and under the responsibility of the Tenderer's Designer, requires in any case the Owner's approval.

For the alternative design offers to be taken into consideration, a 'basic' Tender has to be submitted as well.

The Tender Forms should specify

- if submission of alternative proposals is either allowed or encouraged and, if so, for what parts of the Works;
- the limitations and requirements to be considered in the alternative;
- the alternatives 'a priori' unacceptable;
- the documents required with the alternative proposal and the contractual conditions for its acceptance;
- the criteria and parameters to be used by the Owner in deciding the "economically" most advantageous Tender.

Variations during the works

In addition to the variability included in the 5 % range indicated above, which has no influence on the final price, variations during the Works can be allowed - subject always to the Designer's approval - for the following reasons:

- price variations in respect of the expected contract sum due to variations of actually measured quantities for each "typical section" vis-a-vis those indicated in the Bill, provided they are within the variability limits defined for the project (see sect. H.11);

Variations within the amount limits and scope of article 25, comma 3 of the Law 216/95 (5 %);

- laws or regulations subsequent to the Award;
- unforeseen or unforeseeable conditions (art. 25, 1b, L. 216/95);
- geological unforeseeable conditions (art. 1664, comma 2 of Civil Code);
- errors and/or omissions of the detailed design which are in toto or in part prejudicial to either the completion or the use of the Works. In such case the Engineer must so advise forthwith the Owner's delegated Executive, who will immediately notify the relevant Authorities and the Designer.

---

* Documents L.1 and L.7 shall be submitted in a separate sealed envelope, to be opened only for the Tenderers qualified in terms of the remaining documentation.

2 The 5 % fluctuation has been set to help both the Contractor to be able to suggest occasional and/or complementary special measures and the Engineer to instruct an increase of such measures, as and when required. This would avoid the need to define both the new prices and the variations of the contract sum. Within the same limit, the Engineer shall also be able to authorise a reduction of such measures.

O. Contract documentation

In addition to the general conditions and the conditions of particular application (if any), the Contract Documentation for underground Works must include:

- the special conditions and specifications defining "inter alia" (but not limited to);
  - the scope of Works;
  - the specifications of the various types of work involved (Technical Norms and Standards);
  - the evaluation standards;
- the priced Bill of Quantities.

P. The underground works

The realisation of an underground structure comprises the following main construction phases:

- the underground excavation;
- the stabilisation measures;
- the permanent lining;
- the waterproofing and improvement of the ground around the opening;
- the ancillary works (portals, plant, etc.).

P.1 The underground excavation

P.1.1 Tunnels

A distinction must be made between conventional excavation, using either explosives (drill and blast with or without pre-splitting, smooth blasting) or not but still employing mechanised (demolition) equipment, and mechanised excavation with either boom-type road headers or full section Tunnel Boring Machines (TBM).

The Design defines whether a full or partialised section has to be used.

P.1.2 Underground chambers

Given the length / section dimensional relationship, the underground chambers are generally excavated by partialised section, with different excavation methods. These range from the conventional (e.g. the 'German') to the more recent using pre-stabilisation, both temporary and permanent, of the opening, now commonly used for powerhouse construction.

P.1.3 Shafts

The shaft excavation methods are listed here according to depth and direction:

SHALLOW	diaphragm wall piling secant piling trenching jet grouting caissons freezing
DEEP	traditional (from top / bottom) pilot drive / raise borer pilot drive / raise borer, plus enlargement
INCLINED	traditional (from top / bottom) TBM from bottom raise borer

P.2 The stabilisation measures

The following tabulation lists the various types of measures, according to the excavation method and their relation to the face:

TRADITIONAL/ ROADHEADER EXCAVATION	ahead of the face	- mechanical spiling - grouting - drainage - micropiling - jet grouting - freezing - pre-mill
	at the face	- shotcreting - dowelling or bolting - fiberglass dowelling - breastboarding - shield
	behind the face	- bolting, dowelling, tendons - shotcreting - shotcreting plus bolting - girders and spiling - girders and shotcreting - girders and bolting (soil nailing) - micropiling - jet grouting - drainage
TBM EXCAVATION	ahead of the face	- mechanical spiling - grouting - drainage - micropiling - jet grouting
	at the face	- pressurisation / thyxotropic muds (Hydroshield, EPB machine)
	behind the face	- bolting - girders and bolting - precast segments - liner plates

P.3 The permanent lining

Concrete is the universal permanent lining for rail and road tunnels.

The table lists instead the various types adopted for hydro - tunnels and chambers.

The distinction is a direct consequence of the different function the lining has according to the final usage. The purpose of the permanent structure, exclusively in the road and rail tunnels, and primarily in the no-pressure hydro-tunnels, is to support the ground loads; this is also valid for the chambers. For the hydro pressure tunnels instead, the essential purpose is to contain the internal hydraulic pressure in order to maintain water-tightness against leakage.

FINAL LINING

HYDRO-TUNNELS	free flow	- concrete
		- reinforced concrete
		- precast segments
	pressure	- reinforced concrete
		- prestressed reinforced concrete
		- Kieser
		- plate or PVC lining
CHAMBERS		- reinforced concrete
		- reinf. concrete (arch), shotcrete + tendons

P.4 The ground surround improvements

The improvements performed ahead of the excavation have the main purpose of modifying the characteristics of the ground so as to ensure better stability and safety for the excavation itself.

Those performed after the permanent lining aim either to achieve a more thorough and uniform ground-structure interaction or to improve specific characteristics (e.g. the watertightness).

Q. Technical specifications and norms

There are in Italy several technical specifications and norms, generally applied and referred to; this practice avoids excessive text content in the Specifications (e.g. UNI, AGI, AICAP, CNR). In case of absence of specific norms, reference can be made to foreign norms (a translation is needed).

From 1998 the specialist foundation work will be furnished with the ECN norms.

The following text provides a proposed guideline for Specifications topics.

Q.1 Materials and construction elements

This section comprises a chapter relating to the general conditions for acceptance, control, supply, temporary stockage and relevant responsibilities. It also has subsections of technical specifications for the following materials and construction components (terminology, list of reference norms, requirements, performances, tests, supply and stockage):

- anchorage
- drainage
- shotcrete, gunite, mesh, fibres
- metallic structures
- concrete and reinforcing steel (rebar)
- precast concrete segments
- grouting mixes
- waterproofing materials.

In particular

- the subsection "anchorage" (either tension or shear elements) comprising, tendons, bolts, dowels specifically characterises types, materials, accessories and appurtenant works;
- the subsection "waterproofing" deals with the following:
  - synthetic membranes
  - sodic benthonite panels
  - benthonitic expansive profiles
  - elastic expansive profiles
  - semirigid PVC panels with ridges
  - liquid or plastic application products
  - bituminous or polymer-bituminous membranes
  - steel liners
  - water-stop joints.

Q.2 Performance of the works

It includes the technical specifications for the performance of the Works listed in Chapter P (terms, reference norms, workmanship, tests).

Indications as to content of some sections are given here.

- Excavation - it may be subdivided as follows:
  - tunnels and chambers (mainly horizontal excavation)
  - shafts and inclined drifts (mainly subvertical excavation).

  For both, reference has to be made to the envisaged excavation methodology:
  - traditional, with either explosives or mechanical equipment (hydraulic hammer, roadheader, ripper, etc.)
- mechanised (TBM, raise-borer, reamer, shield).

In all cases it is essential to define the behavioural characteristics of the various categories as envisaged by the detailed design, to enable appropriate reference in the Bill of Quantities and proper evaluation in the estimating and pricing.

- Overbreak - control methods and convergence measurements
- Presupport ahead of the opening - methods and application criteria for:
  - drainage
  - grouting
  - spilling
  - jet-grouting
  - pre-cut
  - pre-tunnel
  - fiberglass dowels reinforcement
  - etc.
- Support of the opening - methods and application criteria for:
  - shotcrete, gunite, mesh, fibres
  - steel structures
  - precast segments
  - anchorage
  - micropiles
- Waterproofing - specifies the methods of construction and of application of the materials
- Lining - it deals separately with each category of tunnel, either transport- or hydro-types. For pressure hydro-tunnels (and shafts) specifications as to required watertightness are also given. ••